Low Energy Deuteron Photodisintegration


JLab, Rutgers, St Marys, S Carolina, Temple

Motivation

Experimental details

Time request

Summary

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**Context**

- Investigating and understanding the quark/hadron transition in nuclei has been a focus of JLab research.
- Deuteron studies, particularly photo-disintegration, have been primary sources of information on the transition in nuclei; data above 1 GeV are not explained by conventional hadronic theory, but there are 5 competing quark model explanations:
  - 89-019 (PRL 2001), 00-007 (prelim), 00-107 (jeopardy)
  - 03-101 ($^3$He, in queue)
Motivation – “Breakdown” in Hadronic Theory at Low Energy

- Low and intermediate energy deuteron photodisintegration has been extensively studied
  - Many (now mostly) consistent cross sections
  - ~1200 polarization data points
    - Mostly $\Sigma, p_y,$ and $T$

- Generally well understood with modern calculations, particularly the work of Schwamb and Arenhövel, that incorporate:
  - Modern NN potentials
  - Relativity

- (But... )

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Agreement in $ds/d\Omega$

- Low-energy deuteron photodisintegration well understood in modern calculations, particularly the work of Schwamb and Arenhövel: figure from NPA 690, 682 (2001)
- Some poor data, but overall agreement with a few problem regions
Agreement in $\Sigma$

- Low-energy deuteron photodisintegration well understood in modern calculations, particularly the work of Schwamb and Arenhövel: figure from NPA 690, 682 (2001)
- Overall agreement with a few problem regions
Agreement in $\Sigma$

- Schwamb and Arenhövel model works up to $\sim 500$ MeV
- Simpler Kang et al. in qualitative agreement up to 1.4 GeV
Agreement in $p_y^n$

- Low-energy deuteron photodisintegration is generally well understood with modern calculations, particularly the work of Schwamb and Arenhövel: figure from NPA 690, 682 (2001)
Agreement in $C_{x'}$, $C_{z'}$

- Schwamb and Arenhövel agree with the Hall A $\theta_{cm} = 90^\circ$ E89-019 data at 480 MeV, and point towards higher energy data.
- Theory in c.m.

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But...

- ... the situation is not so good for the induced proton polarization

- The discrepancy systematically increases with energy
Problems Emphasized at 90°

• Neither hadronic calculation reproduces data well
• Induced polarization very large near 500 MeV
• Despite some poor \( p_y \) data, it is clear there is a problem

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Comment

- The agreement with $C_{x'}$, but disagreement with $p_y$, near 500 MeV, is odd - these two are the imaginary and real parts of the same combination of amplitudes
  - $\sigma(\theta) C_{x'} = 2 \text{Re} \sum_{i=1,3} (F^*_{i,+} F_{i+3,-} + F_{i,-} F^*_{i+3,+})$
  - $\sigma(\theta) p_y = 2 \text{Im} \sum_{i=1,3} (F^*_{i,+} F_{i+3,-} + F_{i,-} F^*_{i+3,+})$
- Schwamb and Arenhövel predict the magnitude of this combination of amplitudes is small
- The data tells us that the magnitude is about as large as the cross section
- Perhaps the good agreement of the $C_{x'}$ (and $C_{z'}$) data point is fortuitous
Historical Note

- **Most outstanding problem**: the breakdown in the ability to describe the induced proton polarization $p_y$ that starts at $E_y \sim 300$ MeV ($W$-md $\sim 280$ MeV), leading to a peak at $\theta_{cm} = 90^\circ$, $E_y \sim 500$ MeV ($W$-md $\sim 570$ MeV)

- This peak led to the “dibaryon” excitement of the 1970s-1980s; it remains an unexplained, leading indicator of the difficulty awaiting hadronic theory at higher energies
Motivation Summary

- While γd→pn at low energies, up to a few hundred MeV, is understood with conventional hadronic theory, it starts to fail at ~300 MeV, most obviously in pγ - a ~30 year old unsolved problem
- We propose a systematic set of high precision data, to more clearly see how the theory “breaks down”, and give clues to the underlying physics
From H. Arenhövel

- ``I think your proposal is very interesting, because we certainly need more precise data on the outgoing nucleon polarization in that energy region for clarification of the various theoretical treatments. Therefore, I and also Michael Schwamb support wholeheartedly your proposal.''
- ``I only would not call it "low energy" but "intermediate energy". ''
- JLab theory review by F Gross and W van Orden also "enthusiastic" for similar reasons: ``This new data... would be of considerable help''
Experiment Overview

- 10 μA, ~400-500 MeV beam, polarized electrons
- 4% $X_0$ radiator (untagged $\gamma'$s)
- 15 cm LD$_2$ target
- P into HRS with FPP
- Done before: Hall A E89-019, E00-007, ...
- Low energy beam generally impossible to schedule, but target of opportunity: 1 pass beam into Hall A during low energy 1 pass GO run in Hall C
Feasibility – Already Done

- During E89-019, we had 3 hours of beam (2 1/3 hours of production data) at 528 MeV
- 1.2 kHz DAQ rate for 8 μA, 4% photon radiator, LD₂
- The data obtained at θ⁰ = 90° were:
  - P_y = -0.96 ± 0.11
  - C_x' = 0.08 ± 0.04
  - C_z' = 0.10 ± 0.04
- The total acceptance was about 80 MeV, the average photon energy was 480 MeV
Backgrounds

- There is 100 (140) MeV region of photon energy before start of $\gamma d \rightarrow pn\pi^0$ background at forward angles ($90^\circ$)
- End caps rates low, removed by target cuts
- Pions rates are low, and pion momentum is too low at forward angles for pions to be seen
  - TOF in detector stack separates $\pi/p$
- In-target radiator is seen directly for angles $<20^\circ$, otherwise we have had no radiator background problems (no one-bounce problem) in Hall A
Spin-Transport “Problem”

- In HRS, with 45° bend, the spin transport $p_y$ hole is for $\gamma = 1.115$, $T = 108$ MeV, $p = 464$ MeV/c
- Our momentum range is about 500 - 750 MeV/c, so the “natural” size of our $p_y$ uncertainty is $\sim 3 \times$ the size of the polarization-transfer uncertainties
What is Needed?

- Special G0 run intended for summer 2006 shutdown offers opportunity for low energy beam
- $G_E^n$ runs in Hall A spring 2006, hall reconfigured to standard setup summer 2006
- Photon radiator and cryo-target will need to be reinstalled: +few hours
- Front FPP chambers and electronics rack need to be reinstalled: ~3-4 days
  - We do the FPP check out and calibration
  - Expect FPP needed for other expts in 2006-2007
- FPP code currently is old ESPACE FORTRAN, need few months to convert to Hall A root C++ analyzer
20-MeV bins

- Observables strongly energy dependent, so we need small energy bins
- Observed $p_y$ goes from -0.2 at 300 MeV to -1 at 500 MeV, or 0.08 / 20 MeV bin
- Predicted $Cz'$ goes from 0.75 at 230 MeV to 0 at 500 MeV, or ~0.052 / 20 MeV bin
- Final binning will depend on observed energy dependences and measurement uncertainties
  - Estimated resolution for reconstructed $E\gamma$ ~ few MeV
Estimated Uncertainties

- For 585 MeV beam, with standard assumptions plus FPP performance and spin transport
- Uncertainties for each 20 MeV bin
- Program takes 11 days for production yd, plus 3 days for FPP/ep calibrations (also gives $P_{beam}$)
- 5 of 10 angle settings given below, as examples

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Expected Results

- 580 MeV beam, 20 MeV bins, 2 examples below
- $C_x$ and $C_z$ previously basically unmeasured
- More systematic, better precision data for $p_y$
Estimated Uncertainties

- For 360 MeV beam, with standard assumptions plus FPP performance and spin transport
- Uncertainties for each 20 MeV bin
- Program takes 14 days for production gd, plus 3 days for FPP/ep calibrations (also gives $P_{beam}$)
- 5 of 10 angle settings given below, as examples

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Expected Results

- 360 MeV beam, 20 MeV bins, 2 examples below
- $C_x'$ and $C_z'$ previously basically unmeasured
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Why Two Energies

- G0 proposes 2 energy settings, 585 and 360 MeV, plan to run higher energy run first
- It appears what happens afterward depends on the online results of the first part of the experiment
- There are questions about whether parity quality beam will be technically feasible as the beam energy is lowered
- We are not sure what energy will run, but would like to be able to take advantage of whatever energies G0 ultimately uses
TAC Report

- Verify FPP status: We agree - FPP not used since 2002, but also requested for two experiments likely to be scheduled late '06 / early '07
- Multiple low-energy beam feasibility: We agree - have been in contact with accelerator, tests will be needed, but people optimistic
- Radiator/target effect on beam dump: in 1999, beam hitting flow diverters limited radiator; 4 % radiator OK at 530 MeV, expect we will need 3 % at 360 MeV
- Beam polarization: $\Delta C_{x'}, \Delta C_{z'} \ll \Delta p_y$, so it is not necessary to adjust request
Summary: Low Energy $\gamma d \rightarrow pn$

- Induced polarization is a 30-year old unsolved problem; systematic, precise data is the best hope to lead to a solution: 10 c.m. angles $\times$ 5 20-MeV photon energy bins.
- $C_{x'}$ and $C_{z'}$ are nearly unmeasured, and there is valuable information in their comparison with theory.
- $P_{y}$ will be more systematically measured, with improved uncertainties, compared to the previous measurements.
- Requires 14 (17) days at 580 (360) MeV.
- An easy experiment in Hall A that is nearly impossible to do elsewhere; no conflict with other proposals / experiments - if there is low energy $G_0$ run.

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